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COSMIC DUST; RECENT RESEARCH AT THE FRENCH ATOMIC ENERGY COMMISSION **/1

T.Grjébine*

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Theories on the origin of cosmic dust are reviewed. The probability of atmospheric, industrial, desert-sand and other pollution, contribution by volcanic ash, tropospheric or stratospheric homogenization, is eliminated by logical deductions, to prove that the large amounts of dust accretion on land and in marine sediments must be of extraterrestrial (cometary or meteoric) origin. The capture of dust from the toroidal meteor group by the earth, due to difference in form of their orbits, is theorized. An attempt is made to attribute the motion of the earth in space, the appearance of meteors in the atmosphere, and the fallout of radioactive debris to one and the same phenomenon, namely, to an entrainment by magnetic dusts. A Table is given for defining the possible origins of dust fallouts by eliminating improbable sources. Author

1. Historical Aspects

France has been one of the first countries that became interested in cosmic dust.

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* Center for Weak Radioactivity, CNRS (National Center of Scientific Research, Paris).

** Numbers in the margin indicate pagination in the original foreign text.

One year after E.Nordenskjöld who was the first to observe cosmic dusts in 1874, G.Tissandier and S.Meunier discovered and collected on Iceland, far from any industrial center, spherules in the fallouts and in geological sediments. One year later, Sir John Murray detected spherules in the oceanic clays. In 1930, L.Rudeau observed the first correlation between meteors and spherules. Before that, the most significant correlation had been furnished by one of the few comets that ever fell on earth, namely, that of Tunguska in Siberia of the year 1908, which was accompanied by the appearance of spherules.

Several years ago, Villermaux as well as Legrand, Meunier, and Bonpas, published two articles referring to the collection and analysis of magnetic material collected. The collection was made on the outskirts of industrial centers, thus introducing the possibility of industrial pollution, which in itself is quite difficult to determine. For this reason, these two studies did not receive the publicity which they would otherwise have deserved.

The start of our own work has been somewhat slower. On the one hand, we made series of chemical and spectroscopic analyses on microspecimens of materials collected either from fallouts or extracted from geological deposits, or else obtained from marine cores.

On the other hand, samplings made specifically for studying radioactive fallouts were measured. The results, so far as Metropolitan France is concerned, were first published in the Comptes rendus of the Academy of Sciences in Spring of 1963 and later at the occasion of the First Conference on Cosmic Dusts held in New York in November 1963, covering a more general study of magnetic dust /2 fallouts for all of the stations in the French Commonwealth (Fig.1).

Do cosmic dusts constitute micrometeorites?

The main truly abundant fall of meteoric dust collected by us during the past five years, was that of August 1959 (Fig.1). This particularly intense Perseids shower was detected by Crozier at New Mexico, by Kreiken in Turkey, and by more than half of the French stations. The material collected in one of these stations (at Dijon) was particularly abundant; Patureaux of the Mineralogy Laboratory of the Museum of Natural History attempted to detect nickel in this material but was unable to discover even traces.

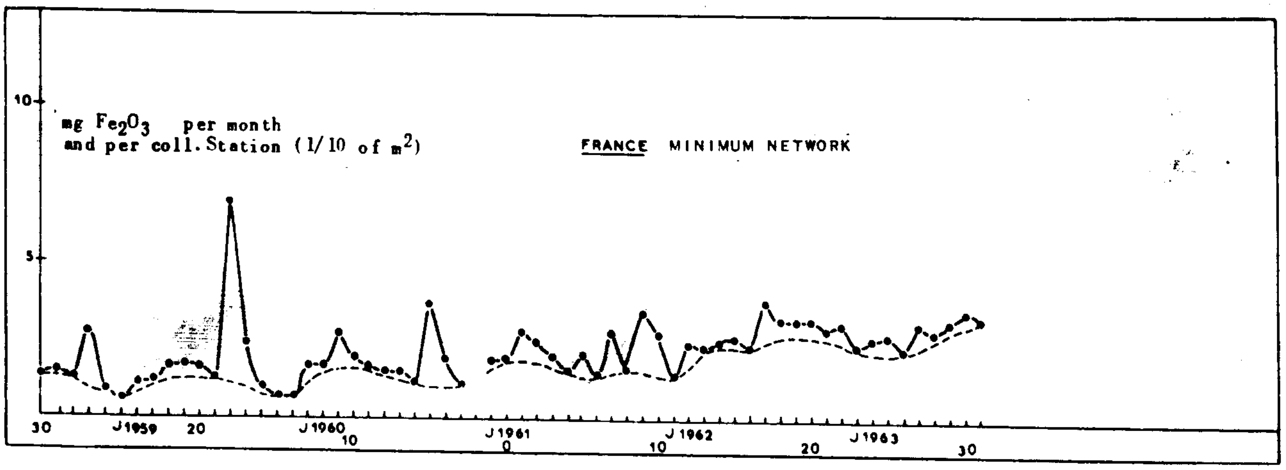

Fig.1 Mean Monthly Magnetic Dust Fallouts for the Network
of French "Minimum" Stations

The second attempt at a detection of nickel, made on our request by M.S.May using the activation analysis method, showed a nickel-iron content of less than 0.1%. At the time, these analyses were quite upsetting since the presence of a large nickel content in the iron was considered a necessary criterion for cosmicity. However, in view of the extent and abundance of this material, there was a strong presumption in favor of its cosmic origin. When Crozier published his studies, it appeared certain that this large fallout was worldwide. The obvious conclusions were that the meteoric material, although highly magnetic, did not contain the high percentage of nickel present in iron meteorites and

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	IN PERCENT IRON METEORITE (KRINOV)	IN PERCENT TROILITE	IN PERCENT GEOLOGICAL DEPOSIT OF MAGNETIC DUST	IN PERCENT GEOLOGICAL DEPOSIT OF MAGNETIC DUST	IN PERCENT MAGNETIC DUST ENTRAINED BY RAIN	IN PERCENT IRON ORE FROM LIBERIA
Na			0.025	0.06	0.25	
Mg	0.03	0.09	0.25	0.5	1.5	
Al	0.04		2			0.51
Si	0.004		30	$\geqslant$ 10	$\geqslant$ 10	1.65
K				0.25	0.4	
Ca	0.05		1	0.5	$\geqslant$ 10	0.2 to 20 %
Ti	0.01		1.25	0.8	0.5	0.09
V	$6\ 10^{-4}$	0.004		0.05	0.03	0.1 to 0.2
Cr	0.03	0.1	0.15	0.05	$\leqslant$ 0.01	0.1 to 0.2
Mn	0.03	0.05	0.2	0.8	0.7	0.1 to 1
Fe	88	63	65	75	$>$ 10	66
Co	0.65	0.01	0.1	0.15	0.02	
Ni	9.5		0.12	0.1	0.08	0.01 to 0.05
Cu	0.03	0.03	0.5	0.4	0.5	0.2 to 0.05
Zn	0.01	0.16	0.6	0.6	0.5	
As	0.03	0.1	0.01	$<$ 0.01	$<$ 0.01	
Mo	0.001	0.001	0.01	0.02	$<$ 0.01	0.015
Ba			0.6	0.3	0.5	
Pb	$6\ 10^{-5}$	0.002	0.1	0.2	0.8	

Fig.2 Overall Composition of Magnetic Dust, Extracted from Clays or Collected in Fallouts

that, consequently, various compositions of cosmic fallouts may exist.

It was of importance to determine whether the composition of this fall of August 1959 represented a particular case or, conversely, whether it was typical for cosmic dusts in the event that these latter did not have the composition of meteorites.

To attempt solving this problem or, at least, to combine some data which would have assisted us in deciding whether the nickel content should or should not be considered a criterion for cosmicity, we made several analyses on various materials.

The analyses concerned a material which we intended to be entirely free of industrial pollution. For this reason, we made a massive extraction of magnetic material in large quantities of Tertiary clays; these dusts were then analyzed by Mrs. Cittanova [C.E.A. (Atomic Energy Commission), Saclay] by optical spectroscopy. Figure 2 gives a comparison of these compositions with those of meteorites and other materials.

The composition of magnetic dusts appeared quite different from that of meteorites. However, it is difficult to believe that this material was not of extraterrestrial origin, which is thus one reason more for us to believe that the high nickel content, in this respect, did not constitute an irrefutable
proof. These highly magnetic particles were not always spherical; in fact, /4
true spheres are quite rare. It has been proved since then that nonspherical forms do exist in space.

After extraction, the magnetic particles extracted from the clays were stored in a water-filled bottle, but placed so as to prevent complete immersion of the uppermost layer. We were greatly surprised to find that the exposed surface changed color within less than one month, going from black to rust brown.

This made us think that, during the fall and transit time within the water, the material in question was only partially oxidized and remained quite close to its initial composition. For this reason, we made a detailed study of these compositions. The point of interest was not so much the low nickel content but the presence of a large number of other elements in appreciable quantities.

METALLICS	SILICATES	ALKALI-METAL AND ALKAL.—EARTH SILICATES	SILICON SULFIDES AND SILICON CHLORIDES	SILICO ALUMINATES AND ALUMINATES	SULFALUMINA AND SILICO-SULFALUMINA	SULFIDES AND CHLORIDES
1 K 1 Ca 4 Fe 6 2 Fe Al 2 Fe Ca 3 Fe Ca Mn 3 1 Fe Ca Ti 1 1 Fe Mn Fe Mn Ti 6 2. Fe Mn Cr Fe Ca Ni 1 1 Ti Fe Ti 1 3 Fe Ni 2 ba Cu 1 Ag 1 Fe Ce Nd La	1 Si Ca 1 Si Ca Mg 2 Si Fe K 1 Si Fe Mg 3 Si Fe 2 2 Si Fe Mn 1 Si Fe Mn Cr Si Fe Mn Ti 2 Si Fe Mn Ti Cr 1 2 Si Fe Cr 1 Si Fe Ni 1 3 Si Fe Ti 1	1 Si Fe Mg 1 Si Fe Mg Cr 1 Si Fe Mg Cr Mo 1 Si Fe Mg Cr Ni 1 Si Fe Ca K 1 Si Fe Ca Mg Ti K 1 Si Fe Ca Mg Cr Ti Co 1 Si Fe Ca Mg Cr Si Fe Ca Mg 2 2 Si Fe Ca K Si Fe Ca Mg K 1 1 Si Fe Ca Cu K 1 Si Fe Ca Cu 7 Si Fe Ca 6 1 Si Fe Ca Ti 4 4 Si Fe Ca Ti Cr 2 Si Fe Ca Ti Cu Si Fe Ca Mn 1 2 Si Fe Ca Mn Ti 1 Si Fe Ca Cr Cu 3 Si Fe Ca Cu 1 Si Fe Ca Ni 1 1 Si Fe Ca Pb Zn	Si Ca S 1 Si Fe S 1 1 Si Fe Ca Mg Ti Ni Cu S 1 Si Fe Ca Ti S Si Fe Ca Mg S 1 1 Si Fe Ca Cu S 1 Si Ca Ti Cl 1 Ca K Cu Cl 2 Si Ti Cl 1 Si Fe Mo Cl 1 Si Fe Ca Co Cl 1 Si Fe Ca Ti Cl 1 Si Fe Ca Ti Cr Zc Cl	1 Al Si K Al Si Ca 1 4 Al Si Fe 10 Al Si Fe K Ni 1 Al Si Fe K Ca Ni 1 1 Al Si Fe K Ca Cr Al Si Fe Mg Ca Ni 1 Al Si Fe Mg Ca 3 Al Si Fe Mg Ti 1 Al Si Fe Mg Mn Cr 1 Al Si Fe Mg Ni 1 5 Al Si Fe Ca 18 2 Al Si Fe Ca Ti 2 3 Al Si Fe Ca Ti Cr 1 Al Si Fe Ca Cr 1 1 Al Si Fe Ca Cr Pb Al Si Fe Ca Mn 1 Al Si Fe Ca K Ni 1 Al Si Fe Ca Ni 1 Al Si Fe Ti 3 1 Al Si Fe Ti Cr Co 1 Al Fe Cr 2 Al Fe Ca	1 Al S 1 Al K S 2 Al Si K S Al Si Fe Mg S 1 Al Si Fe Mg Ni S 1 1 Al Si Fe Ca S 1 1 Al Si Fe Ca Cr Ti S Al Si Fe Ca Mg S 1 1 Al Si Fe Ca Cr Ni S	1 Fe Ni S S 10 1 Ca Co Cl 1 Ca K Cl

Fig.3 Synoptic Table of Spherule Analyses Made with the Castaing Electronic Microprobe
The numerals in front of the formula indicate the number of cases encountered in the spherules of Arctic and Antarctic snows (Langway et al.); the numerals after the formula indicate the number of spherules extracted from Mediterranean sediments (Grjébine et al.)

Silicon was present to at least 30%, in the form of particles obviously composed of a type of silica glass and of iron. Another interesting aspect of a technical nature should be mentioned: It was very difficult if not impossible to dissolve all the dusts in ordinary acids for spectral analysis. Calcium and titanium ranged after iron and silicon, followed immediately by copper, zinc, and barium; it is surprising that we found 0.6% barium and 0.1% lead. It is also odd that we had almost the same quantities of cobalt and nickel.

These results have not yet been published since, because of the fact that they were unexpected, they had to be verified on other specimens. One must always consider the possibility of some unsuspected pollution. Other specimens are now being investigated and, within a short time, a complete series of analyses will be published.

To clarify the problem of the nickel, we removed spherules from oceanic cores. In fact, it was on this type of sample that the first correlation had been observed.

Figure 3 is a synoptic Table, grouping all spherules analyzed by us on microspecimens, including those analyzed by Langway, Hodge, and Wright. The extremely low number of nickel-iron spherules is striking.

Other analyses on spherules extracted from polar ice, whose results were reported during the New York conference by Chester Langway, Frances Wright, and Paul W.Hodge, showed similar compositions.

Whereas the nickel content as a criterion of cosmicity could be eliminated, these latter analyses (118 spherules and fragments examined by Wright, Hodge, /5
Langway and 127 spherules studied by Grjébine, Lalou, Ros, Capitant) yielded completely unexpected results: In fact, certain elements were present in the spherules in associations unknown on earth, mixtures of sulfur, iron, and silico-aluminates, etc. Thus, within a relatively short time it should be possible to define a new cosmicity criterion, based on anomalous chemical associations*.

At first sight, it seems that the different compositions could be correlated with the principal mineralogical families, and the synoptic Table actually

* Since then, this subject was covered in a paper presented at the Congress on Cosmic Dust at Heidelberg (1965).

was compiled with this in mind. However, a closer examination showed clearly that these groups do not always represent stable associations. In all probability, the elements present in a given spherule are condensed there in accordance with random laws or in accordance with a geochemistry differing completely from terrestrial geochemistry; it is obvious that no selection and sorting of elements, as would have taken place in a body undergoing fusion under terrestrial conditions of pressure and temperature, ever took place. These considerations permit the definition of a cosmicity criterion, while also giving a satisfactory historical background for the origin of the collected dusts.

Another interesting aspect is revealed on comparing our results with those obtained by Wright, Hodge, and Langway. The first work was concerned with spherules collected in the upper atmosphere and in polar ice, while the second study centered on spherules extracted from marine sediments.

In 118 analyzed particles, Wright et al. found 75 categories whereas the 127 particles analyzed by us only permitted a classification into 42 categories. The two analysis methods are so similar that the ratios $\frac{118}{75} = 1.5$ and $\frac{127}{42} = 3$ have a good chance of being of true physical significance.

In fact, two different explanations might be offered: Wright and coworkers worked on particles larger than ours and with a larger number of different elements per particle, thus increasing the chances of encountering more categories (for 1.5 particle on the average). We studied particles about twice as small as those investigated by Wright and found a new category for each third particle. Thus, it can be stated that the number of categories is more or less proportional to the dimensions and to the probability of having various associations of elements. The second explanation would involve corrosion.

2. Corrosion

On the other hand, it is well possible that the dimensions of our particles were smaller since many among them did not have a chance of reaching the bottom of the ocean and thus were subject to corrosion. Such corrosion would leave intact only the most resistant particles.

The number of spherules per gram of sediment, in the cores Nos.24 and 13, again illustrates the effect of corrosion.

The core No.13 was taken in a Lutecian sediment, located at a depth of 2615 m. The core No.24 comes from a more rapid sedimentation zone, at the foot of the Continental Slope. The mean was 269 spherules per gram in the specimen No.13, and 466 spherules per gram in the specimen No.24. In other words, the number of spherules increases with the rate of sedimentation. This difference is significant. In fact, we demonstrated that, in the core No.13, the number of spherules varied in inverse proportion to the coarse fraction, which would indicate that the spherules are more or less diluted in the terrigenous detritic matter.

In other words, corrosion destroys more than half of the cosmic particles*.

This explains the fact that, despite the low nickel content of the spherules, the correlation between the number of spherules and the total nickel content of the sediment persists. The spherules in the sediments present only the most resistant portion of the matter which, coming from cosmic space, has been introduced into the oceans.

Petterson thought of this and, in collaboration with Rotschi, published an

* Since then, this subject was covered in a paper presented at the Congress of the International Committee of Scientific Studies of the Mediterranean, Monaco, October 1964.

article on the abnormal rate of nickel in sediments of the Pacific Ocean. On /6 this point, our results agreed with his.

For a long time, microscopic cosmic matter was considered a mere curiosity and no one ever thought that this might be the principal source of matter constituting the sediments of the Central Oceanic Regions.

a) Total Mass of Cosmic Dust Falling on the Earth

The estimates as to the total mass of accretion on earth varies by a factor of 10^9 among the various authors, a variation due mainly to the methods used. Even the estimates by one and the same author, H.Petterson, varied by a factor of 10^5 depending on the methods used by him.

In our first evaluation of the total accreted mass, we made use of the radioactive debris collecting network C.R.A.P.A.L. of the Atomic Energy Commission. This C.R.A.P.A.L. network comprises 24 stations in France and 30 stations in the former territories of Overseas France.

The collectors themselves are made of Plexiglas, with an opening of 1/10 m^2. The opening of the collector is covered with sterilized gauze. At the bottom of the vessel, there is a wad of cotton and a container with an ion-exchange resin.

The gauze and the cotton are calcined and the ashes are weighed on a magnetic balance. This calcination reduces the magnetism of the dust specimens by 10% on the average, but the magnetic weighing of these collections permitted a rapid measurement of the dust, without preweighing and without destruction of the specimens.

The stations are located in National Meteorological Parks. The collectors, relative to radioactive debris, have furnished data comparable to those obtained by other methods [adhesive tape(Venus fly trap), water traps]; thus, it was possible to estimate them as representative of the surface that they represent.

In this fashion, we have refuted all restrictive hypotheses, such as the necessity of the object being spherical.

The only certain characteristic of a cosmic dust is that it arrives from space. At the beginning, it is thus natural to start the study of cosmic dusts by simply investigating the dust fallouts, no matter of what type, and to analyze exclusively the variations as a function of time and location.

The method of magnetic weighing had various advantages over simple weighing: The method is more sensitive and permits direct working on the filter, without any pretreatment. The magnetism of the dusts is relatively limited in time, in view of the fact that the iron oxides are converted into hydroxides which reduces the magnetism by a factor of 1000. Therefore, the magnetic weighing favors so-called "fresh" dusts rather than dusts of the soil whose magnetism has been attenuated.

In view of the fact that we are not looking for individual particles, it is impossible to distinguish cosmic dusts from terrestrial and industrial dusts, except by analyzing them from the geographical and chronological viewpoint.

We also collected dusts on board commercial and naval vessels, equipped with scientific instrumentation and forming part of French polar expeditions.

Toward the end of 1962, the measurements made over a period of five years in the C.R.A.P.A.L. stations in France could be subdivided into two groups. The values of the first group were equivalent to about 2 mg of Fe_2O_3-gamma per C.R.A.P.A.L. and per month. This group is localized on the French Atlantic Coast, in cultivated regions without industry or having industry operating only on natural gas from Lacq. On the basis of the mean values of the results obtained with this group, we made our first estimate of a cosmic accretion of

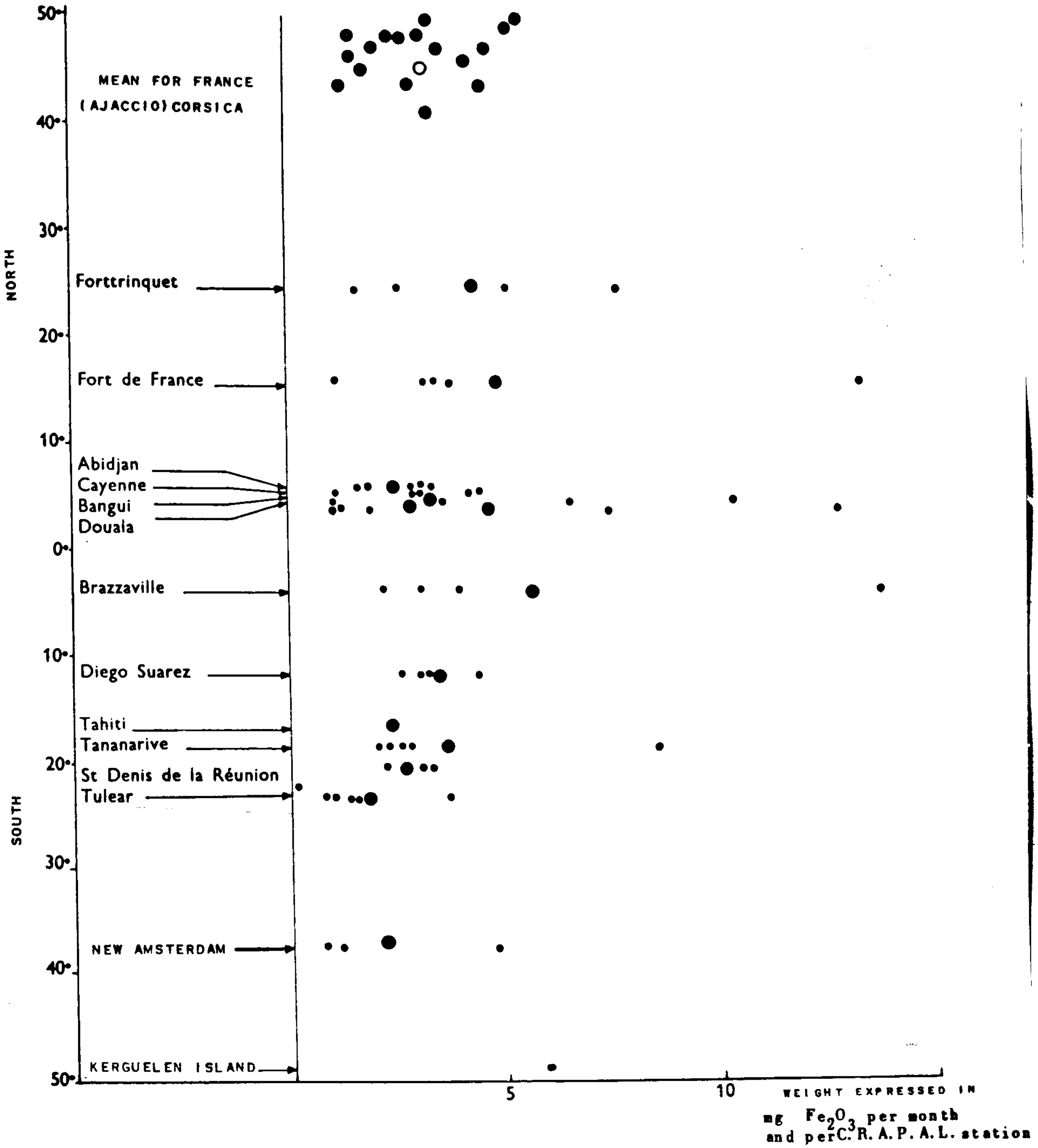

Fig.4 Mean of Magnetic Fallouts over Five Years, for the Entire Worldwide Network

2.4×10^9 tons per year (Bibl.8); see Fig.1*.

The second group yielded values higher than 2 mg and of much greater variety. The collectors in question were placed underground and frequently downwind of industrial zones, which thus might constitute an index of industrial pollution. Local meteorological conditions might greatly influence the quantity of dust collected. This is the case specifically for radioactive debris, so that it is understandable that large scattering of data exists for the various stations.

The data obtained in the overseas stations (Fig.4) indicate that the mean obtained for the French stations is closed to the worldwide mean. Excluding the Sahara and a portion North of the Sudan, where aeolian erosion is significant, the mean values taken over a period of four years in the overseas stations are of the same order of magnitude as the figures obtained for France.

Stations such as Tahiti, Diégo-Suarez, Tuléar, Tananarive, Réunion Island, New Amsterdam, were shown to be free of pollution. /8

Such a constant distribution of magnetic dusts over the surface of the globe is striking. After converting the magnetic quantities into real weights of the substance (conversion made with a quantity of dust sufficiently large for being magnetically weighed and measured), the result is a total rate of deposit of 2.4×10^9 tons/yr for the entire earth or 4.8 gm/m^2 per year as a worldwide value.

3. Possibility of Aeolian Pollution

In France, the possibility of wind-borne pollution is negligible. The soil

* Since then, T.A.Mutch, making estimates on the basis of the number of spherules contained in the saline deposits of the Primary Era, found a rate of accretion amounting also to 10^9 tons per year, or even more in some cases.

is humid and covered with vegetation in the oceanic coastal regions (first group). There are no denuded slopes. Occasionally, rains charged with a reddish dust have been observed, generally presumed to be of Saharian origin. The last of such rains occurred in April 1962. The nature of this odd phenomenon is uncertain.

Aeolian pollution is hardly possible for the overseas stations below 10^{o} Lat.N.

4. Possibilities of Industrial Pollution

With respect to the overseas stations, industrial pollution is impossible. In fact, there are no local dusts of industrial origin and, in addition, the hypothesis of a pollution coming from far away is untenable since the total quantity of magnetic fallouts is much too great to be attributed to industry; this is true for all ashes in general.

It is difficult to believe that this pollution, if it were industrial, could be distributed so uniformly over the two Hemispheres. It is known, from studies on radioactive debris, that even these fallouts take a relatively long time to cross the equator.

So far as Metropolitan France is concerned, the total amount of dusts introduced into the atmosphere is quite accurately known. The National Power Co. of France, so as to prevent any claims and lawsuits, keeps accurate daily statistics on fly ash emitted by its own installations and by other sources, such as the French Railways, private industry, and domestic housing. For France, the proportion of such fly ash is not sufficiently high to justify the quantity of dust detected by the collectors.

5. Magnetic Dust over the Oceans

The measurements made in August and September 1963 on board the ships of the Compagnie Générale Transatlantique (General Transatlantic Company) and the Compagnie des Messageries Maritimes sur l'Océan Atlantique (Atlantic Maritime Transport Company) are plotted in Fig.5 as a function of the latitude.

These curves show the following:

1) The density of the magnetic dust in the air is extremely variable. In this respect, the magnetic dust behaves exactly as the radioactive debris.

2) The concentration of dusts collected over the ocean is higher than that encountered on terra firma. Additional experiments are scheduled for checking these highly surprising results.

6. Rate of Fall

The quantity of dust falling each day on a collector can be theoretically enclosed in an equivalent column of the same cross section as the collector whose height is given by the altitude from which a dust particle of average size may fall to the ground within one day.

This will produce a column of 1880 m height, falling each day on the collector, which is equivalent to a rate of 78.5 m per day. For radioactive debris, the same column would have a mean height of 1300 m. This coincidence is striking. The velocity in question is considerable and explains why transport over large distances is practically impossible. This rate seems in good agreement with the results of calculations based on Stokes' law. The agreement with the rate of fall of radioactive debris would be even better if, for the filter, we would assume a 100% stopping power for magnetic dusts. This rapid rate of /9 fall is another argument contradicting the possibility of a transport mechanism over long distances.

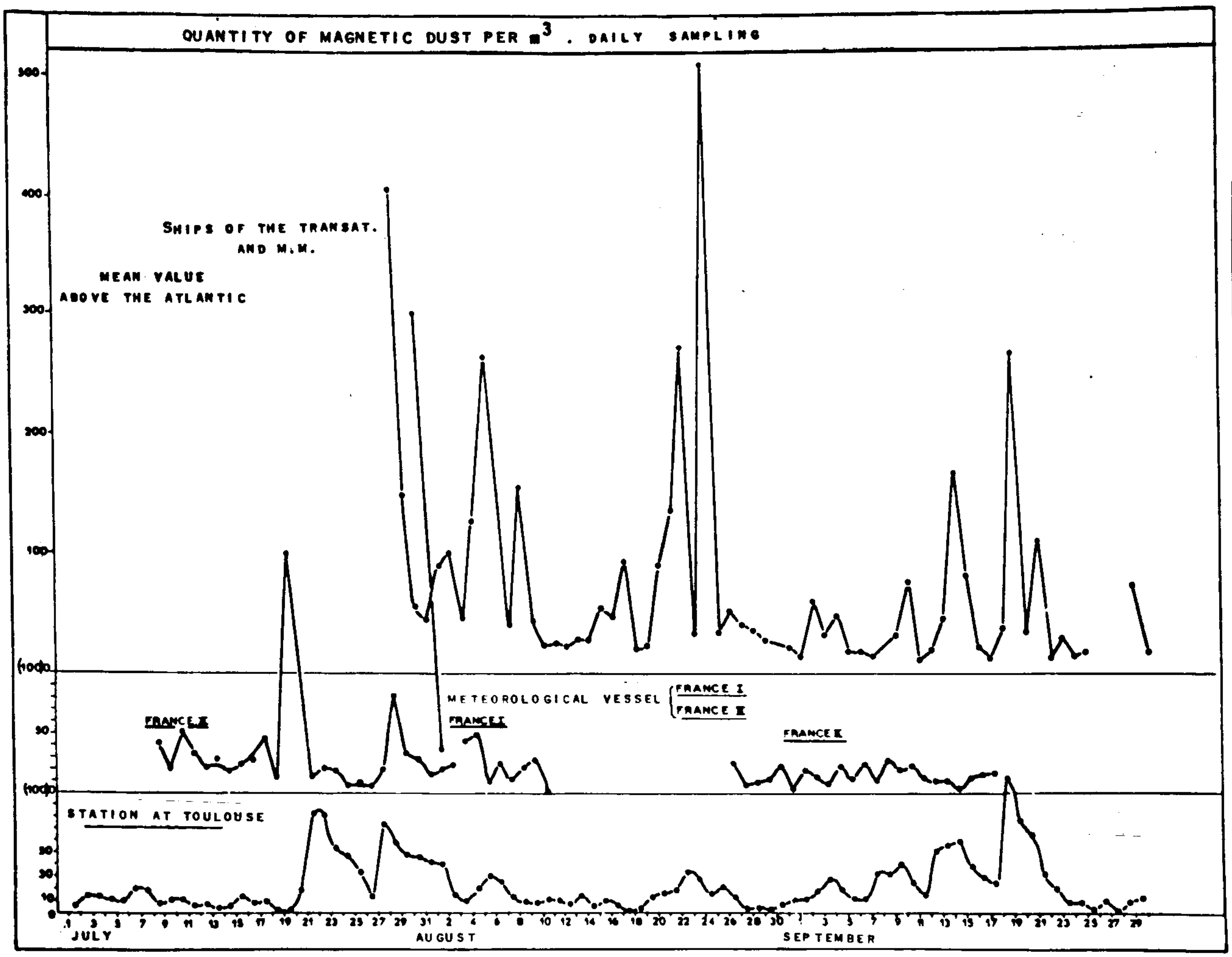

Fig.5 Variation in the Quantity of Magnetic Dust in the Air above the Atlantic, Compared to Toulouse

It is of interest to note that, if H.Petterson had taken a shorter residence time for his calculations, his accretion rate would have been comparable to our own values.

7. Chronological and Geographical Correlations

The high rate of fall of magnetic dusts excludes any tropospheric homogenization. The quantity of dust, falling on the individual stations, varies greatly. This means that no stratospheric homogenization takes place and that the mean residence time in the stratosphere probably is very short. If this were not the case, the dusts would obey the same distribution law as the aged radioactive debris and would fall on all stations at a much more uniform abundance.

The fact that certain peaks, as that of August 1959 (Perseids shower), were observed by Crozier in New Mexico, by Kreiken at Ankara in Turkey, and by ourselves in France and in Madagascar, can be attributed to the assumption that a part of the dust present in the atmosphere is introduced on a worldwide scale; however, here again, no mixing can be the cause since the durations of such peaks are much too brief.

In view of the improbability of long residence times, any significant /10 contribution of volcanic origin is also out of the question. The logs kept in chronological order since August 1958 do not coincide with the chronology of volcanic eruptions.

The values published with respect to cosmic accretion on earth are on the increase since a few years, in keeping with the gradual elimination of the limitations inherent to the techniques used (for example, corrosion of particles in salt water, limitation in dimensions by filtering and resolution of the countings, limitations inherent to all types of magnetic separation). Dusts collected by rockets, balloons, and high-altitude aircraft show that particles much smaller than those previously considered actually do exist. The resolution of electronic microscopes imposes a limit on such evaluations. If the size distribution, integrated in accordance with MacCraken and coworkers, is extrapolated to small dimensions, a mass of accretion much larger than previously estimated will be obtained. Such an extrapolation is justified since, in addition to micrometeorites, the presence of nanometeorites has also been observed. In addition, some of these samples contained matter in a form undetectable even by the electron microscope. This matter could not have been detected except for the heat generated by electron bombardment which caused melting of the matter, reducing it to minuscule and compact spherules of the order of a few hundred angstroms. In addition, iron was detected*.

In Fig.6, various estimates of the yearly accretion of mass on earth are compiled. The columns show the different limiting factors introduced by a number of authors: corrosion of specimens taken from the ocean or from other saline deposits. The dust samples collected and returned to earth by rockets indicated that the spherical form was only one of the possible shapes, which means that the estimates based exclusively on spherules certainly are not within the realm of reality.

Evaluations of dust densities around the earth, made by means of satellites, differed greatly. The values of the flux vary as a function of the mode of particle detection: by photomultiplier, by microphonic counter, by surface monitor, or by perforated detectors. So long as we do not know the exact shape of cosmic dust - hollow spherules, fragments, filaments - we will not be able to standardize accurately what we detect. In any case, the finest dusts are never detected and, as indicated above, much higher figures than our own are obtained on extrapolating the satellite data to small dimensions. In calculating the mass of accretion on the basis of density of the dust (around the earth), certain

* Since then, estimates based on the abundance of matter contained in noctilucent clouds, composed of dust of cosmic origin at 100 km altitude, indicated an even greater percentage of small particles.

Annual Terrestrial Accretion, in Tons			Limiting Factors	Corrosion	Magnetic Extraction	Shape	Size	Chemical Composition	Rate of Fall	Direction of Flux	Astronomic Normalization
2.5 10^{9}	Grjebine	1963	?								
1,4 10^{8}	Villermaux	1959	2		x		x				
1.4 10^{7}	Petterson	1960	2					x	x		
5. 10^{6}	Petterson	1960	2					x	x		
3.6 10^{6}	Mc Cracken Alexander	1961	2				x			x	
3.6 10^{6}	Mirtov	1962	2				x			x	
3,6 10^{6}	La Gow Alexander	1960	2				x			x	
3,6 10^{6}	Dubin	1960	2				x			x	
3.6 10^{6}	Whipple	1960	2				x			x	
3.6 10^{6}	Watson	1956	?								X
3.6 10^{6}	Van de Hulst	1947	?								X
3,1 10^{6}	Kreiken	1959	2			x	x				
2. 10^{6}	Thomsen	1953	2			x	x				
1.8 10^{6}	Mayne	1956	2?					x			X
5. 10^{5}	Hodge Wildt	1958	2			x	x				
3.6 10^{5}	Fesenkov	1960	?								X
3.6 10^{5}	de Jager	1955	?								X
2.8 10^{5}	Norris Hogg	1949	2			x	x				
2.5 10^{5}	Opick	1956	?								X
2. 10^{5}	Wright Hodge	1962	2			x	x				
1.8 10^{5}	Thiel Schmit	1961	2			x	x				
1.6 10^{5}	Crozier	1962	3		x	x	x				
1.5 10^{5}	Crozier	1960	3		x	x	x				
1.2 10^{5}	Buddhue	1950	3		x	x	x				
9 . 10^{4}	Crozier	1961	3		x	x	x				
4 10^{4}	Petterson Rotchi	1950	4	x	x	x	x				
3 10^{4}	Fireman Kistner	1961	2					x	x		
1.4 10^{4}	Astapovitch	1958	?								
1. 10^{4}	Watson	1939	?								X
7 10^{3}	Best	1960	?								X
5,8 10^{3}	Petterson Fredrikson	1958	4	x	x	x	x				
3.6 10^{3}	Fesenkov	1960	?								X
3.1 10^{3}	Wylie	1935	?								X
3. 10^{3}	Petterson	1960	4	x	x	x	x				
5.6 10^{2}	Watson	1941	?								X
1.8 10^{2}	Milleman	1948	?								X
1.7 10^{2}	Opick	1956	?								X
1.2 10^{2}	Petterson	1953	4	x	x	x	x				
30	Brun	1955	4	x	x	x	x				
8	Buddhue	1950	3		x	x	x				

Fig.6 Total Mass Collected by the Earth per Year, according to Various Authors and Different Means Used, with the Limitations Introduced by the Methods

authors again arrived at higher values. The measurements made on board satellites yielded no data on the direction of flux of the dust circulating about the earth. It is highly important to know this direction, so as to prevent an incorrect conversion of the mass flux arriving at the earth's surface.

8. Rate of Sedimentation

The rate of accretion of 2.4×10^9 ton/yr gives a rate of sedimentation of 2.4 mm per 1000 years assuming a sediment density equal to 2, which fairly well agrees with the observed rates of sedimentation at the same latitudes in both the Atlantic and the Pacific Ocean. This rate, presuming that it is constant, would produce the formation of a layer of about 7 km thickness since the beginning of the geological ages. This thickness is surprisingly similar to the depth of oceanic layers above the Mohorovicic discontinuity.

It is of interest to note that several authors (Van Hilten 1963, Carey 1958, Heezen 1959, Hilgenberg 1962), in starting from an entirely different discipline, namely, that of paleomagnetism, arrived at a similar estimate of increase in the earth's radius (2 km) since geological times. It is highly probable that this increase has not been constant, which would further reduce the difference between the results.

9. Origin /12

To review our observations and to evaluate the probability of possible different origins of magnetic dusts, we compiled a Table giving the possible origins in vertical columns and the characteristics of the magnetic dust in horizontal rows. This Table permits to eliminate a possible origin each time that an observed characteristic does not agree with the presumed origin.

Only extraterrestrial origins are never excluded. However, cosmic origins may vary widely. These include: the sun, the zodiacal cloud, the various classes of meteors, the comets, the meteorites, the moon, etc. The ablation of stone and iron meteorites cannot furnish appreciable quantities; studies made on the Grant meteorite show that only a layer of 2 - 6 cm has been removed by ablation. On the other hand, Parkin and Hunter demonstrated in 1962 that, even if the entire mass of a meteorite entering the terrestrial atmosphere were converted into spherules, this volume would still be insufficient to account for the numerous spherules that fall on the earth each year. Thus, for statistical reasons and for reasons of chemical composition, we must exclude a meteoritic origin for this dust. A lunar origin has never been investigated.

A cometary or meteoric origin seems more probable. The correlations with meteor showers and, specifically, the ratio of 0.3 observed between the peaks and the slow variations in the curve of magnetic dust fallouts established for France, seem to indicate that meteor showers and sporadic meteors (ratio 0.26) (24) might be significant sources.

The principal difference between meteoric and meteoritic materials is that the former are not located, like the meteorites and asteroids, in the plane of the ecliptic. This difference may well be the prime explication for the differences in origin and composition. Up to now, so far as naked-eye meteors are concerned, Opick was the only one to make measurements of hyperbolic velocity, meaning that these measurements, apart from any other results, do not show the existence of interstellar meteors. However, these observations referred only to meteors of appreciable size. The problem of orbits of sporadic meteors and particularly of orbits of radiometeors of very small dimension, appears even more complicated. The crew at Jodrell Bank and later that at Harvard reported the existence of a so-called "toroidal" group whose orbits are highly peculiar.

This group consists of a meteor population of small dimensions which arrive in the plane of the ecliptic with a 60° N inclination. Until now, no origin has been suggested for this particular group. We are not specialists in radioastronomy but would nevertheless like to advance a suggestion: It might be possible to establish a correlation between this group and the movement of the earth about the sun, which is an oblique helicoidal motion with an inclination of 40°. The dust present in interstellar space would thus be collected by the solar system and by the earth.

This fine dust would be attracted toward the solar system and, at the same time, would be decelerated by the solar radiation pressure and the solar wind, in view of the fact that the dimensions of the particles are reduced and, apparently, the dust is not massive but is characterized by a high surface/mass ratio (see the work by Verniani). Presumably, this deceleration is not negligible. Although this deceleration can be calculated only if the form assumed by the dust particles in space were known, it should be completely sufficient to make the meteors of the toroidal group exhibit orbits and velocities that no longer are hyperbolic.

Such a deceleration would permit capture of the dust by the planet. The resultant motion could be of the type of "criss-cross pattern" known as the toroidal group. The final distribution of the dusts over the soil would be due to an influence of the magnetic field and of the Van Allen belts; the surplus in the Northern Hemisphere, due to meteors, would thus be drained and descend toward the soil in a preferential direction at 45° N.

On the earth itself, we have three types of observation available which might possibly be correlated with these dusts. These are: distribution of

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Characteristics of Spherules and Correlations		Origin	Industrial	Atmospheric	Fluvial	Volcanic	Biogenic	Meteoritic	Meteoric, Cosmic
Oceanographic Data	Deposits in ancient geological strata		No						
	Spherical forms			No	No				
	Continuous series, opposing the coarse fraction		No	No	No		No		
	Proportionality with respect to dissolved matter		No			No			
	Spherules with 0.1 - 0.2% nickel content							No	
Data on Contemporaneous Deposits	Fallouts on the entire earth		No	No	No		No		
	Rate of fall		No	No	No	No	No		
	Higher values above the oceans		No	No	No	No	No		
	Continuous series since 1958				No	No			
	No homogenization				No	No			
	Magnetism of the soil of the surface stratum		No	No					
			Impossible origins:				No		Yes

Fig.7 Truth Table for Possible Origins of Spherules

Fig.8 Collection Station on the Island of Ré

radioactive debris of atomic bombs along the meridians; distribution of natural radioactive products; distribution of products formed by cosmic radiation (beryllium-7). The three distributions are quite similar, showing two maxima approximately at 40°; the maximum of the Northern Hemisphere is more pronounced than that of the Southern Hemisphere. It is naturally possible that the explanation should be looked for quite simply within the atmosphere, and numerous (in fact too many) explanations have been published on this point. However, /15 it would be difficult to understand how a purely atmospheric process could lead to a disequilibrium between North and South as pronounced as that observed with all radioactive tracers.

We have demonstrated that the rate of fall of magnetic dusts is quite close to the velocity of radioactive debris, so that one would be tempted to assume that the magnetic dusts might constitute a vehicle of "heavy rain" for the debris, entraining them toward the ground. In this case, it could be understood that the motion of the earth in space, the appearance of meteors in the atmosphere, and the fall of radioactive products on the earth are manifestations of one and the same phenomenon.

However, at present we are still far from such a synthetic theory. To start with, it must be sufficient to keep this theory in mind since it might serve later in the preparation of new experiments.

We have not spoken of the effects of cosmic dust in meteorology and, in a more general manner, in climatology, but this is a very vast topic (one might as well speak of the lunar surface).

In conclusion, we would like to mention that we are in favor of an international cooperation in the field of observation and collection of dusts over the entire world. In fact, we have prepared a project in this direction.